Original Article

Journal of the Tsuruma HEALTH SCI. MED. KANAZAWA UNIV. Vol. 2
75～90 200

Electromyographic and biomechanical analyses of forward lunge in three foot positions

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ABSTRACT

The present study was undertaken to biomechanically and electromyographically analyze the patterns of a forward lunge. Using the optimization method and the musculoskeletal model this study was also designed to estimate the muscular tension during the forward lunge and to analyze the relationship between the estimated muscular tension and electromyographic recordings. Eighteen healthy men performed the forward lunge exercise using three different foot positions, namely the toe-in, neutral and toe-out positions. The author analyzed activity patterns of the vastus lateralis(VL), vastus medialis(VM), rectus femoris(RF), biceps femoris(BF), the medial head of the gastrocnemius(GCM) and tibialis anterior(TA), in addition to the patterns of joint moment during the exercise. Furthermore, the correlation between the estimated value for the muscle tension and the root mean square(RMS) value for the electromyograms were analyzed during the lunge. The vastus lateralis, VM, RF and TA were found to be markedly active in all of the foot positions during the lunge, though RF was less active than VL and VM. On the contrary, the activity of BF and GCM was small. Knee extensor moment for the toe-in position was significantly larger than that for the other two foot positions. Ankle plantarflexior moment for the toe-in position was significantly smaller than that for the other two foot positions. The coefficient of correlation between the estimated muscular tension and electromyographic RMS ranged from 0.58 to 0.61 for VL, from 0.55 to 0.67 for VM and from 0.22 to 0.39 for RF, respectively, which was statistically significant for all of these muscles. In conclusion, the forward lunge could be used in the development of rehabilitation strategies for clients with weakness of the quadriceps femoris and TA.

KEY WORDS

Electromyography, Forward lunge, Joint moment

Introduction

The knee joint constitutes an intermediate joint of the lower extremity, and stability of this joint is required during walking or in sports activities. The static support mechanism of the knee is provided by an arrangement of ligaments[1]. The dynamic stability of the knee in the valgus direction has been shown to involve the muscles on the medial side of the knee (e. g., the sartorius, gracilis, semitendinosus, semimembranosus and medial head of the gastrocnemius), whereas in the varus direction it involves the muscles on the lateral side of the knee (e.g., the biceps femoris and the lateral head of the gastrocnemius) and in the anteroposterior direction the quadricep femoris and the knee flexors[2].

The quadriceps femoris is the major muscle ir volved in knee extension. It is composed of fo muscles, i.e., the vastus medialis (VM), vastus lateral (VL), rectus femoris (RF) and vastus intermedius (VI Of these muscles, VM plays an important role in pr tecting and supporting the knee[3], as well as su pressing lateral deviation of the patella[3]. VM h also been shown to be more vulnerable to atropl than the other three heads of the quadriceps femo

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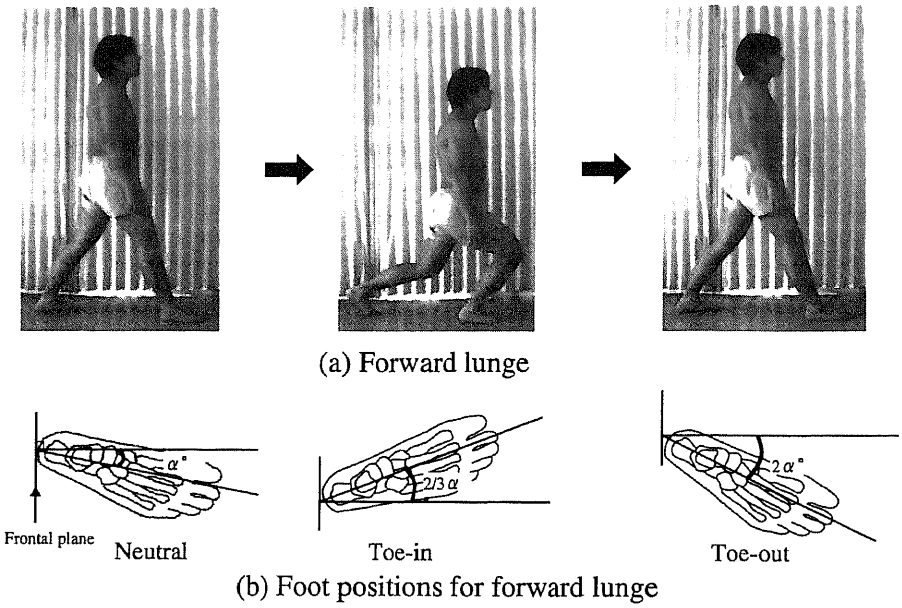


Fig. 1. Method of the forward lunge in the three foot positions.
α : The foot angle in natural erect position

and responds more slowly to strengthening exercises than VL[4-7]. Therefore, attention to training of quadriceps is often directed to VM rather than the other three heads of this muscle.

Muscle strengthening exercise can be divided into open kinetic chain (OKC) and closed kinetic chain (CKC) exercises, both of which have been defined by Steindler[8]. CKC exercises are a more practical means of strengthening muscles than OKC exercises. Both squats and forward lunges are representative of CKC exercises, but clinical use of the latter is limited compared to that of the former. Forward lunges place a greater load on one leg than squats, therefore, potentially producing a greater effect on muscle strengthening than the latter. Furthermore, since forward lunge requires a preliminary lead-in step, it is closer to the natural body action taken while playing sports or in daily life. The lunge has also been used for functional assessment of individuals with injured anterior cruciate ligaments[9]. However, few reports of biomechanical and electromyographic analyses of the forward lunge have been published, and there are hardly any published analyses of the forward lunge in various foot positions.

The present study was therefore undertaken to biomechanically and electromyographically analyze the forward lunge in three different foot positions. This study was also designed to estimate muscular tension during the forward lunge using the musculoskeletal model and the optimization method, and to analyze the relationship between estimated muscular tension and electromyographic (EMG) activities. The musculoskeletal model refers to a rigid link model of a human body with the additional concept of length and attachment of muscles based on data from those of a cadaver. The optimization method, normally used in the field of engineering, is defined as a method in which muscular tension is estimated using optimized values derived from data on tension and a physiological cross-sectional area of muscles.

Subjects and Methods

Participants

Eighteen healthy men with no history of any orthopedic condition of either knee were enrolled in this study. They all gave their consent to participate in the experiment after having been informed of the methods of measurement and the exercises involved. The mean age of the participants was 20.6±1.4, ranging from 19 to 25 years.

Procedure

1) Exercise

The exercise analyzed in this study was the

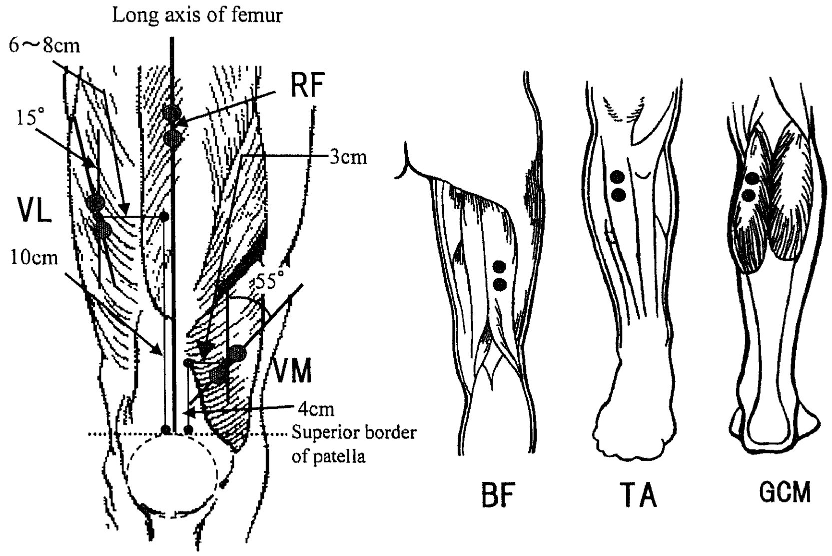


Fig. 2. Electrode placement for VL, VM, RF, BF, TA and GCM.
The electrode for VM was placed over the muscle belly approximately 4cm superior to and 3 cm medial to the superomedial border of the patella, and orientated 55° to the vertical. The electrode for VL was placed 10cm superior and 6 to 8cm lateral to the superior border of the patella, and orientated 15° to the vertical. The electrode for BF was placed in a long vertical oval area (6-8cm in diameter) on the lateral side of the dorsum of the thigh (approximately at its midpoint). The electrode for TA was placed on a long narrow oval area whose upper part was one- to two-finger breadth from the tibial tuberosity. The electrode for GCM was placed on the belly of the medial head of the gastrocnemius.

forward lunge with flexion and extension of the right knee in step standing with the right leg placed forward. The participant practiced the forward lunge in three different foot positions (Fig. 1). The natural foot angle was determined as an angle formed by the second metatarsal and a line perpendicular to the frontal plane with the participant in normal standing. The three foot positions for testing were defined as follows : 1) the toe-straight position or neutral, where the angle formed by the second metatarsal and the line perpendicular to the frontal plane overlapped with the natural foot angle, 2) the toe-in position, where the second metatarsal rotated medially, relative to the line perpendicular to the frontal plane, with an angle equivalent to two-thirds of the natural foot angle, and 3) the toe-out position, where the second metatarsal rotated laterally, relative to the line perpendicular to the frontal plane with an angle equivalent to twice the natural foot angle. Each participant performed consecutively 15 to 20 forward lunges at a rate of 25 per minute synchronized by a digital metronome. When performing forward lunges, the participant was instructed to place as much of his weight as possible on the forward leg and to flex the knee by at leasl 75 degrees (°). During the forward lunge, the knees were kept in a direction perpendicular to the frontal plane as much as possible, regardless of which three foot positions was taken. Instruction was given to the participants to keep their tibia rotated inwardly in the toe-in position and outwardly in the toe-out position Furthermore, the participants were instructed to avoic rotating the pelvis as much as possible and to keer the upper trunk as vertical to the floor as possible during the exercise. The participants were given adequate opportunity to practice the exercise before the testing.

2) Electromyography

The right leg muscles were the subjects of EMG Bipolar electrodes were placed on VM, VL and RI of the quadriceps femoris, biceps femoris (BF), me dial head of the gastrocnemius (GCM) and tibialis an terior (TA). The distance between the electrodes an the diameter of the electrodes was 20 mm and 1 mm, respectively. The electrodes for RF, BF, TA an GCM were placed on the sites recommended b Basmajian[10](Fig. 2). The electrodes for VM and V

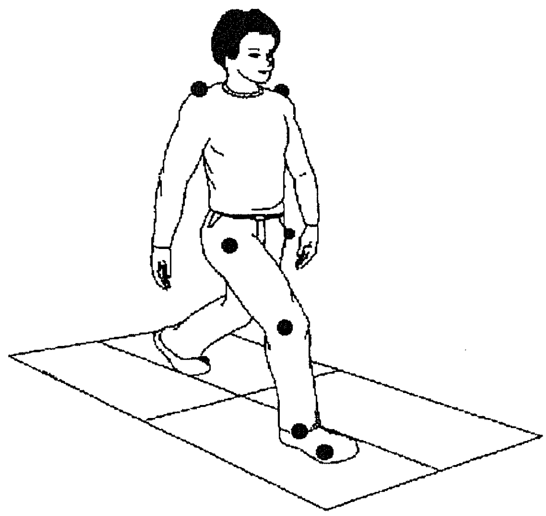


Fig. 3. Positions of the spherical markers for the motion analysis.

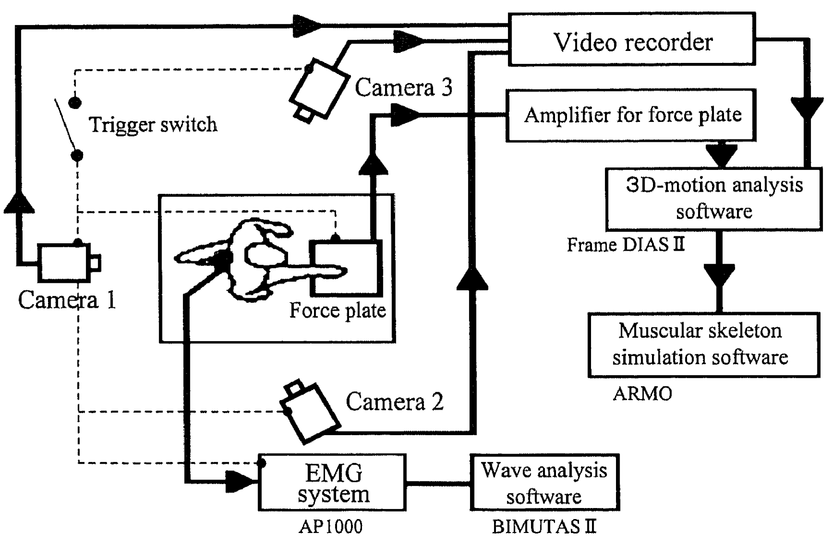


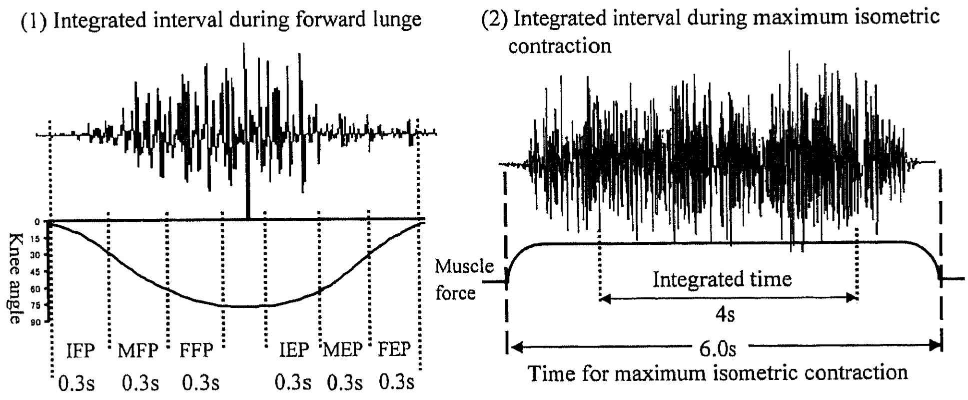
Fig. 4. Experimental system for the analysis of the forward lunge.

were placed on the points used by Cowan et al.[11](Fig. 2). The EMG recording was carried out during maximum voluntary isometric contraction (MVC) and the forward lunge. The EMG signal during MVC was recorded for 6 seconds while flexion and extension of the knee and plantar- and dorsiflexion of the ankle were performed.

In order to stabilize the joints during MVC the Cybex 750 NORM system was used. For flexion and extension of the knee, the participant was seated with the trunk, pelvis and thigh stabilized with a belt. The participant assumed the prone position for plantarflexion and dorsiflexion of the ankle with the trunk, pelvis and thigh stabilized with a belt. During MVC of the knee flexors and extensors, the knee was maintained at 60° for extensor contraction and at 30° for flexor contraction. The ankle was maintained at 5° dorsiflexion during MVC of the dorsiflexors and at 10° plantarflexion during MVC of the plantarflexors.

3) Motion analysis

A spherical reflective marker was bilaterally placed on the fifth metatarsal, lateral malleolus, lateral epicondyle of the femur, greater trochanter and acromion (Fig. 3). Three still cameras operating 125



(3) Method of calculation for normalization

$$\%\mathrm{IEMG} = \frac{\mathrm{IEMG_L}/0.3}{\mathrm{IEMG_{Max}}/4} \times 100$$

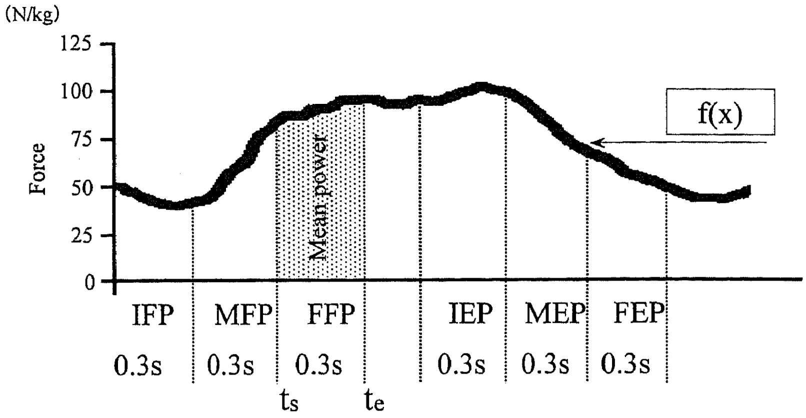
Fig. 5. Method of normalization for electromyographic recordings.
%IEMG : Normalized value of the integrated electromyographic recordings.
$\mathrm{IEMG_L}$: Value of the integrated electromyographic recordings during the forward lunge.
$\mathrm{IEMG_{max}}$: Value of the integrated electromyographic recordings during isometric contraction.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

frames per second were used to record the movement of forward lunge. The image data from the 3 video cameras were stored on videotape. The position of each marker was reproduced on a three-dimensional coordinate on the computer screen, using the motion analysis program Frame-DIAS II (DKH Corp.). During forward lunge, the ground reaction force of the right leg was recorded on a force plate (9286AA, Kistler) synchronized with activation of the cameras (Fig. 4). The analog signals from the force plate were converted to digital ones with a resolving power of 16 bits at a sampling rate of 1000 Hz. Data were then re-sampled at a rate of 125 Hz.

Data processing and analysis

The EMG recording of one forward lunge motion showing maximum vertical components of the ground reaction force was the subject for the analysis. The EMG signals during forward lunge were normalized by those during MVC (Fig. 5). The EMG patterns were processed using BIMUTAS II (Kissei Com-Tech Co., Ltd.). The forward lunge action was divided into flexion and extension phases with each phase being subdivided into three 0.3-second segments, namely, initial flexion (IFP), intermediate flexion (MFP), final flexion (FFP), initial extension(IEP), intermediate extension (MEP) and final extension (FEP) periods. In addition to integrating the EMG signal for a 0.3-second period in each period the EMG signal during MCV was integrated for a 4-second period, excluding the initial one second and final one second. In order to calculate the amount of the muscular activity the integrated EMG (IEMG) value was converted into a one-second rate (%EMG) during the forward lunge and MVC. Further, by dividing the one-second rate of IEMG during the forward lunge by that during MVC it normalized the converted EMG values. To compare muscular activity patterns during the forward lunge with the three foot positions, the EMG signals were rectified and digitally low-pass filtered at 6Hz and normalized with the time required for the forward lunge being deemed as 100 percent (%).

The patterns of the ground reaction force were integrated in each period (IFP, MEP, FFP, IEP, MEP and FEP) and were divided by the integrated period or 0.3 seconds to yield mean power (Fig. 6).



$$\text{Mean power} = \frac{\int_{ts}^{te} f(x)}{0.3} \quad (\text{N/kg})$$

Fig. 6. Method of calculation for mean power.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

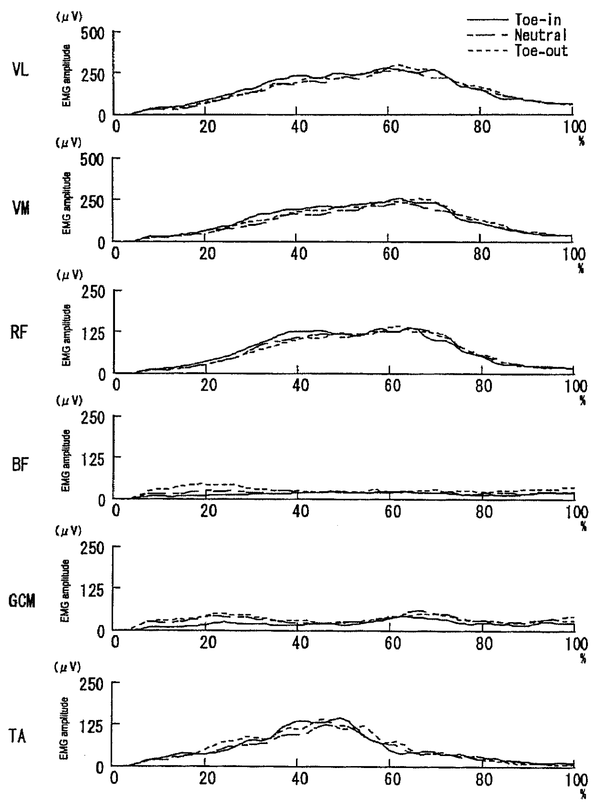


Fig. 7. Patterns of the muscular activity for the three foot positions.
VL : Vastus lateralis, VM : Vastus medialis, RF : Rectus femoris.
BF : Biceps femoris, GCM : Medial head of gastrocnemius, TA : Tibialis anterior.

Joint moments were calculated using the rigid link model and a two-dimensional inverse dynamics method on the basis of information about the location of each segment and the data for the ground reaction force. The muscular tension was estimated by equilibrium of the joint moment, making use of the musculoskeletal model combined with data from Delp et al.[12], Hoy et al.[13] and Wickiewicz et al.[14] and the optimization method. The ARMO (GSPORT Inc.) program was employed for these calculations.

The one-way analysis of variance was used to compare the data among the three foot positions. Fisher's PLSD post-hoc test was employed, followed by multiple comparisons. The level of significance was set at 5%. The results were analyzed using the Statistical Package for the Social Sciences, version 11.0J.

Results

Joint angle and angular velocity (Tables 1 and 2)

There was no difference in the maximum flexion angle or maximum angular velocity of the hip, knee and ankle during forward lunge in the three foot positions.

Activity of the muscles tested

1) Patterns of the muscular activity (Fig. 7)

The activity of VL, VM and RF was largest during

Table 1 : Comparison of joint angle among the three foot positions during the forward lunge.

Foot position	Hip flexion angle (deg)	Knee flexion angle (deg)	Ankle dorsiflexion angle (deg)
Toe-in	42.1± 8.8	78.2±5.1	16.9±6.5
Neutral	41.6±10.8	80.6±6.0	16.4±7.3
Toe-out	42.9±10.7	81.7±5.5	12.9±8.8

Table 2 : Comparison of angular velocity among the three foot positions.

		Angular velocity (deg/s)		
	Foot position	Hip	Knee	Ankle
Flexion phase	Toe-in	39.7±11.4	108.3±15.7	83.0±15.0
	Neutral	39.8±12.4	110.4±14.1	81.7±14.6
	Toe-out	47.0±13.6	116.6±14.0	76.0±16.1
Extension phase	Toe-in	37.0± 7.9	112.2±20.4	78.0±11.4
	Neutral	33.8± 8.0	116.8±22.5	77.2±12.6
	Toe-out	37.3± 9.2	122.3±19.0	71.8±16.2

FFP and IEP, but that of BF remained unchanged during exercise. The activity of BF was found to be slightly larger during IFP in the toe-out position. The activity of TA reached a peak during FFP and decreased during extension. The activity of GCM was found to be small during FFP and IEP, but larger during MFP or MEP. The activity of GCM showed a biphasic pattern in the neutral and toe-out positions, whereas it was found to be monophasic in the toe-in position.

2) Amount of the muscular activity (Figs. 8, 9, 10, 11, 12 and 13)

In each foot position, the normalized value of $IEMG_{VL}$, $IEMG_{VM}$ and $IEMG_{RF}$ was found to be greatest during FFP of the flexion phase and during IEP of the extension phase, yielding 70% or greater (%$IEMG_{VL}$ and %$IEMG_{VM}$) and 50% or greater (%$IEMG_{RF}$) activity. The normalized value of $IEMG_{BF}$ remained largely unchanged at approximately 20% throughout the forward lunge. On the whole, the normalized value of $IEMG_{GCM}$ was found to be small, which was similar to that of $IEMG_{BF}$, but was found to be greatest during IEP. The normalized value of $IEMG^{TA}$ during the flexion phase was found to be greater for MFP and FFP, but tended to be smaller during the extension phase. Only the normalized value of IEMG of both BF and GCM during IFP showed significant differences among the three foot positions.

Ground reaction forces (Fig. 14)

1) Horizontal component (Fx)

The pattern of Fx was found to be similar for all of the toe-in, neutral and toe-out positions. However, the ground reaction force during forward lunge was found to be always smaller in the toe-in position than for the neutral and toe-out positions.

2) Anteroposterior and vertical components (Fy and Fz)

The patterns of Fy and Fz did not differ significantly between any two of the toe-in, neutral and toe-

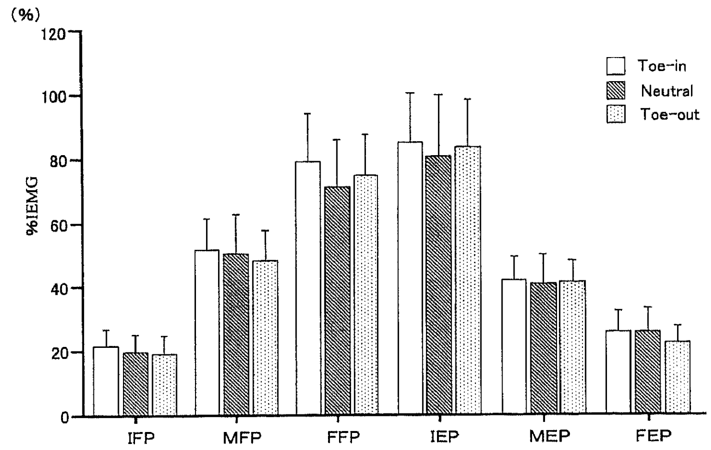


Fig. 8. Comparison of the normalized IEMG for the vastus lateralis among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

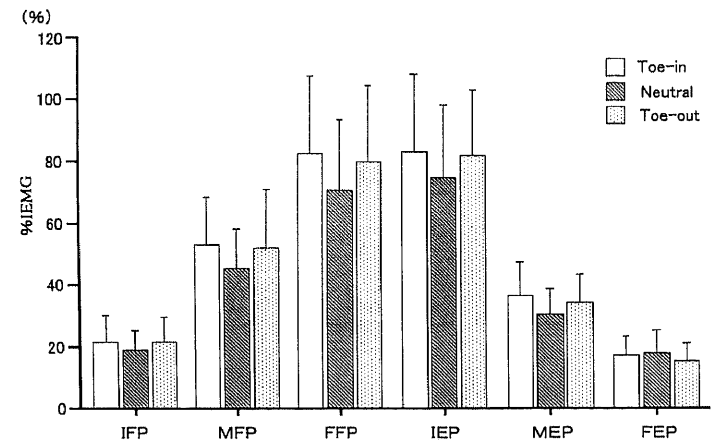


Fig. 9. Comparison of the normalized IEMG for the vastus medialis among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

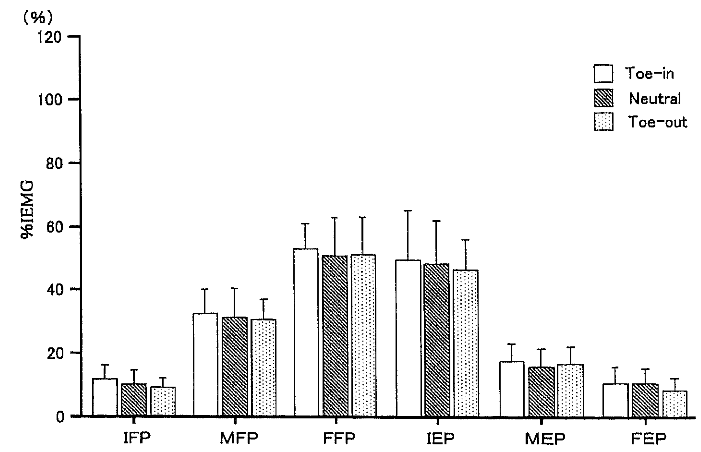


Fig. 10. Comparison of the normalized IEMG for the rectus femoris among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

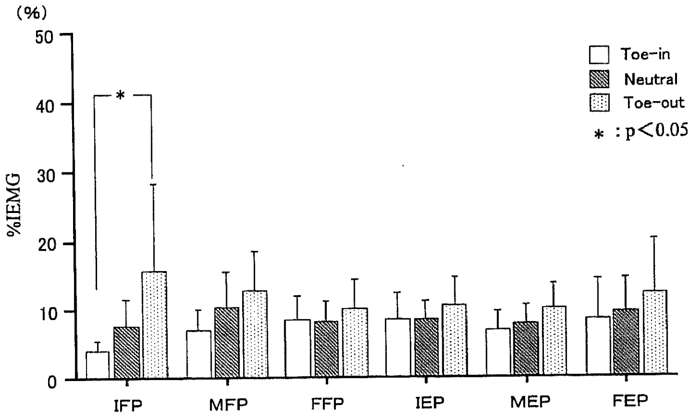


Fig. 11. Comparison of the normalized IEMG for the biceps femoris among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

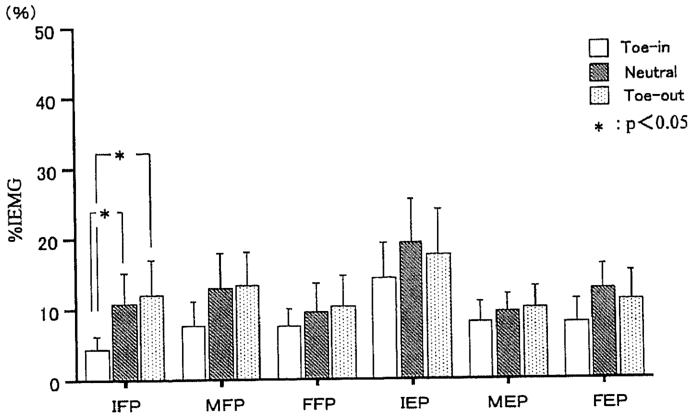


Fig. 12. Comparison of the normalized IEMG for the medial head of the gastrocnemius among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

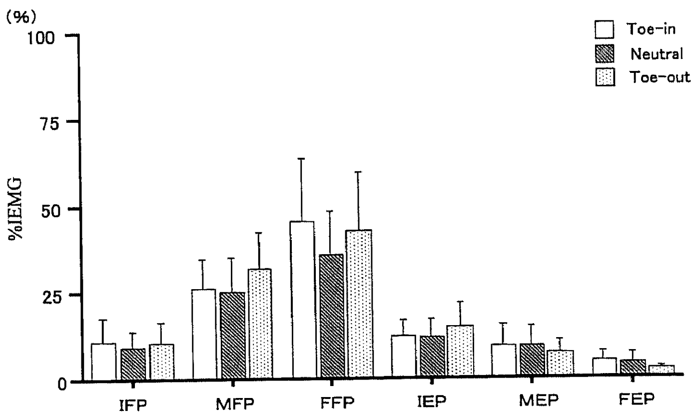


Fig. 13. Comparison of the normalized IEMG for the tibialis anterior among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

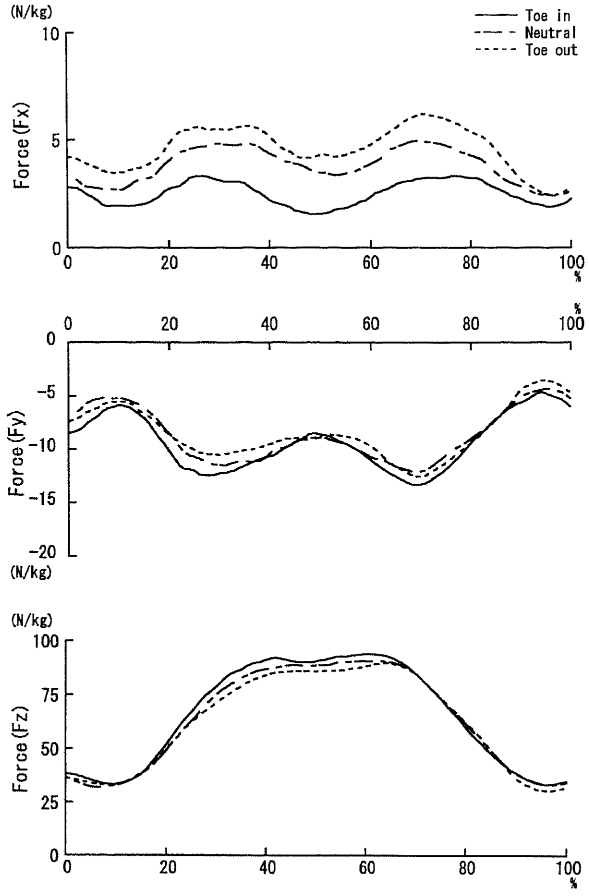


Fig. 14. The ground reaction force for the three foot positions.
Fx : Lateral component, Fy : Anteroposterior component, Fz : Vertical component.

out positions. The maximum load was found to be 93%, 90% and 88% of the body weight in toe-in, neutral and toe-out positions, respectively.

3) Mean power (Fig. 15)

The mean power of Fx was found to be significantly smaller in the toe-in position than for the other foot positions during all periods except for FEP. There was no significant difference in the mean power of Fy or Fz between any two of the foot positions.

4) Joint moment

The joint moment of the hip muscles in the sagittal plane served as that of extensors and never as that of flexors. In the frontal plane the joint moment was of the adductors during IFP and FEP and abductors during MEF and MEP. The joint moment of the knee muscles served as that of flexors during IFP and FEP and as that of extensors during MFP and MEP. The joint moment of the ankle muscles was always that of plantarflexors. The knee extensor moment was greater in the toe-in position than in the toe-out position. The ankle plantarflexor moment was greater in the toe-out position than in the toe-in position. The relationship between the magnitude of the moment around the knee and that around the ankle was reversed in toe-in and toe-out positions (Fig. 16).

In a comparison between the maximum knee extensor moment and the maximum ankle plantarflexor

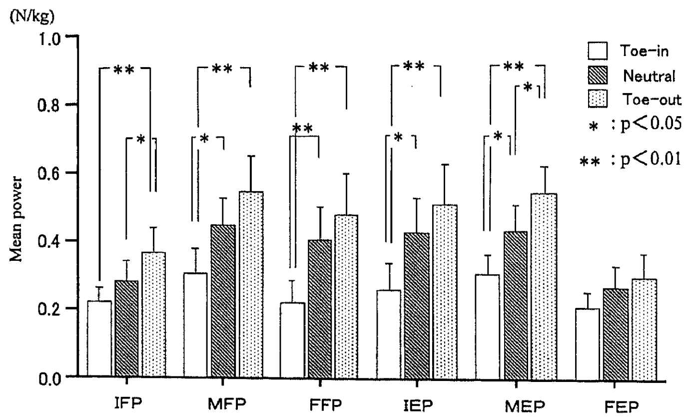


Fig. 15. Comparison of mean power among the three foot positions.
Values are means±standard deviation.
IFP : Initial flexion phase, MFP : Intermediate flexion phase, FFP : Final flexion phase.
IEP : Initial extension phase, MEP : Intermediate extension phase, FEP : Final extension phase.

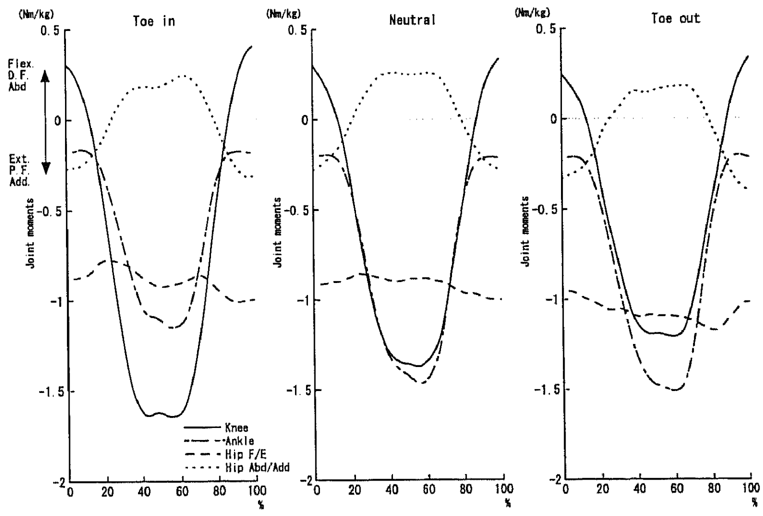


Fig. 16. The joint moment during one cycle of the forward lunge

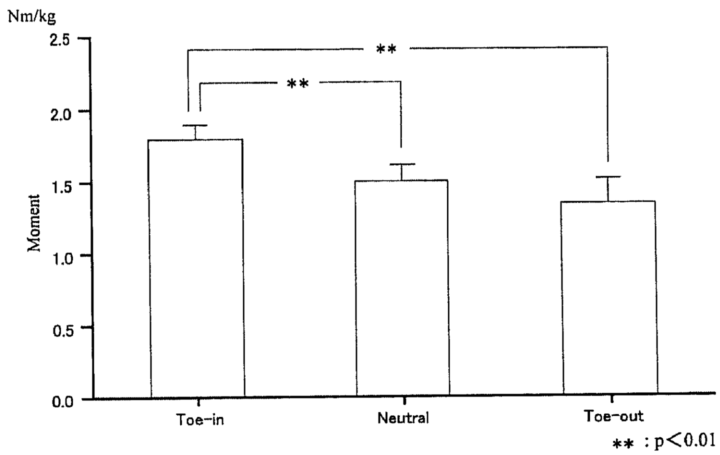


Fig. 17. Comparison of the maximum knee extensor moment.
Values are means±standard deviation.

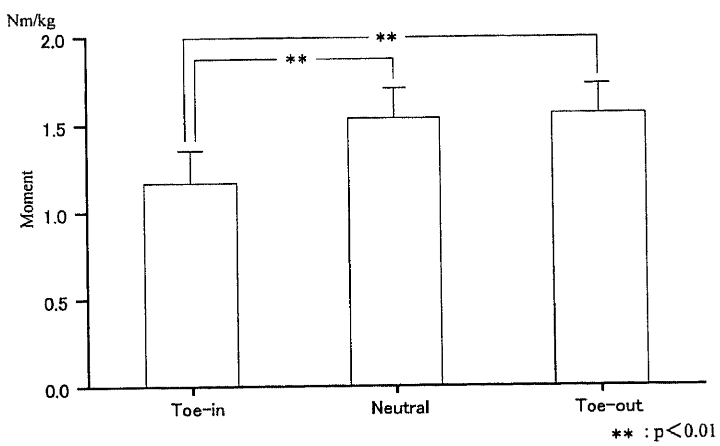


Fig. 18. Comparison of the moment around the ankle among the three foot positions.
Values are means±standard deviation.

Table 3 : Coefficient of correlation between estimated muscular tension and electromyographic values.

Toe-in

	RF	VM	VL
Flexion phase	0.372**	0.585**	0.606**
Extension phase	0.238**	0.670**	0.615**

Neutral

	RF	VM	VL
Flexion phase	0.358**	0.551**	0.575**
Extension phase	0.390**	0.608**	0.584**

Toe-out

	RF	VM	VL
Flexion phase	0.349**	0.627**	0.597**
Extension phase	0.221**	0.651**	0.584**

** : $p<0.01$

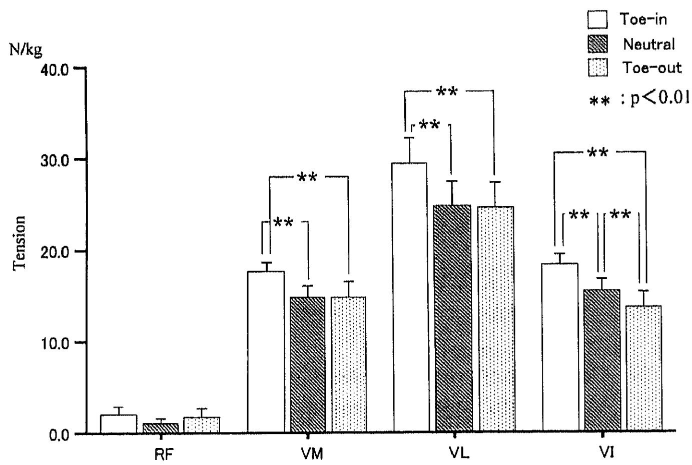


Fig. 19. Comparison of the muscular tension among the three foot positions.
Values are means±standard deviation.
RF : Rectus femoris, VM : Vastus medialis, VL : Vastus lateralis, VI : Vastus intermedius.

moment during the forward lunge among the three foot positions, the former was significantly greater in the toe-in position than in the neutral and toe-out positions (Fig. 17). The maximum ankle plantarflexor moment was significantly smaller in the toe-in position than in the neutral and toe-out positions (Fig. 18).

5. Relationship between the estimated muscular tension and EMG recordings (Table 3)

To analyze the relationship between the estimated muscular tension of the quadriceps femoris and EMG, the root mean square (RMS) was calculated from the EMG value at an interval of 8 ms. VL, VM and RF showed a significant correlation between the estimated strength and RMS, while the correlation for RF was found to be smaller with coefficient of correlation for VL and VM ranging from 0.22 to 0.39. The coefficient of correlation for VL and VM ranged from 0.55 to 0.67.

6) Comparison of the estimated muscular strength

among the three foot positions (Fig. 19)

The estimated muscular strength for VL, VM and VI was significantly greater in the toe-in position than in the neutral and toe-out positions.

Discussion

The patterns of the muscular activity during the forward lunge remained the same regardless of the foot positions. VL, VM and RF showed peak activity during the final flexion and initial extension periods. The level of the peak activity was found to be 82%, 78% and 51% for VL, VM and RF, respectively. A similar finding has been shown by Escamilla et al.[15] and Isear et al.[16]. During the forward lunge, the hip and knee remained in flexion constantly, and the moment around the knee was found to be the one for extensors, except for the periods immediately after the commencement of the lunge movement and immediately before its termination. These findings indicate that the motion during the forward lunge mainly involves the quadriceps femoris, but that RF, which is a biarticular muscle, is also active as a hip flexor. For this reason, suppression of the activity of RF was required to produce adequate knee extensor moment. This may explain why the RF activity was smaller than that of VL and VM.

A similar view about the suppression of RF activity was proposed by Fujiwara et al.[17] and Wretenberg et al[18]. Also the activity of BF and GCM was found to be small throughout the exercise, similar to the results reported by Ikezoe et al.[19] and Alkja[9]. The former authors[19] reported that the activity of TA was approximately 10% of the activity during MVC when it was measured at a point where the center of foot pressure was 70% from the heel in squatting. Considering that joint moment of the ankle during forward lunge always serves as that of plantarflexion, we expected that the activity of TA during forward lunge would be small. However, the TA activity was found to be larger during flexion than during extension, and its activity during the final flexion period for MVC ranged from 35% to 45% of the activity. On postural control of humans, Brooks[20] reported that the forward movement of the erect body involves unified activity of TA and quadriceps femoris, while the backward movement involves the unified movement of the triceps surae and hamstrings. Considering that forward lunge involves both anteroposterior and vertical movements, the relatively large activity of TA during flexion may be explained by the requirement of its activity as a force to produce anterior rotation of the leg muscles and as a muscle to control the posture during forward movement.

The ankle plantarflexor moment was found to be large during the final flexion and initial extension periods. However, the activity of GCM was found to be smaller during the periods where the plantarflexor moment was large. GCM, a biarticular muscle, causes flexion of the knee if its activity is large. During forward lunge, the knee extensor moment was maximal when the plantarflexor moment was maximal. This suggested that the activity of GCM was suppressed when the plantarflexor moment was maximal, so that the generation of the knee flexor moment due to large GCM activity could be prevented. In this connection, Miaki et al.[21] reported that the activity of the soleus was found to be larger during knee flexion than extension, and that the rate of activity of the entire muscles involved in plantarflexion during knee flexion was larger than that of the gastrocnemius. It is therefore likely that monoarticular muscles such as the soleus and the peroneus longus become more active when the plantarflexor moment reaches a peak during forward lunge.

The maximum knee extensor moment and maximum moment around the ankle causing plantarflexion differed significantly among the foot positions. The knee extensor moment was found to be greater in the toe-in than in the toe-out positions, while the plantarflexor moment was smaller in the toe-in than in toe-out positions. The point of application of the ground reaction force was closer to the ankle and more distant to the knee in the toe-in position. This may be the reason why the knee extensor moment was large in the toe-in position and the plantarflexor moment was small in this foot position (Fig. 20).

The measurement of moment allows us to estimate the muscles that are primarily active around a given joint. However, it is impossible to identify a specific muscle or muscles exactly on the basis of moment alone. To obtain information about this point, measurement of muscular activity during motion would be

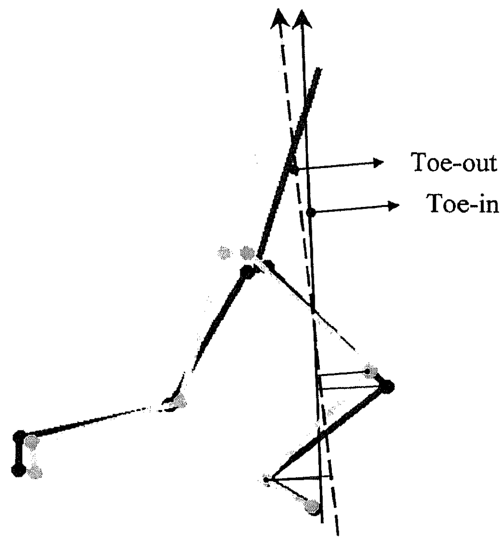


Fig. 20. Lines of action for the reaction force during the forward lunge.

required[22]. In the present study, the maximum ankle plantarflexor moment and maximum knee extensor moment differed significantly depending on the foot position, while the quadriceps femoris and GCM showed no difference in their EMG activities regardless of the foot positions. In the toe-in position, the hip extensor moment was found to be greater as knee extension increased. In the neutral and toe-out positions, the moment around the hip tended to increase gradually during the initial flexion period to the intermediate extension period. The mean power of the horizontal component for the ground reaction force was significantly smaller in the toe-in position than in the neutral and toe-out positions. This finding suggested that the force dispersion in the horizontal direction is smaller in the toe-in position. Therefore, the hip extensor moment in the toe-in position might have played a role in reinforcing knee extension, and the activity of the quadriceps femoris, an agonist of knee extension, hardly increased with the co-contraction of the hip and knee extensors. Thus, this finding might have been the cause of there being no statistical difference among the foot positions. The differences between the results for GCM and those for the plantarflexor moment suggests the possibility of the activity differing among monoarticular plantarflexors, rather than a biarticular muscle such as the gastrocnemius. However, this factor could not be analyzed in this study, since electromyograms were not recorded for the gluteus maximus, soleus or peroneus longus.

The kind of stimuli to the human body varies depending on the type of squatting[23-25]. The same can be said for forward lunge, and muscular activity may vary depending on the form of forward lunge. Ikezoe et al.[26] reported that the activity of the gluteus maximus, gluteus medius and hamstrings were larger as the velocity of squat was more rapid. The rates of squatting in the study by Ikezoe et al. were set at 15, 30 and 45 times per minute[26]. In the present study, forward lunge was performed at a rate of 25 times per minute. Although the type of exercise differed between the present study and that by Ikezoe et al., the rate of forward lunge in the present study might have facilitated the activity of the gluteus maximus. Therefore, the activity of the quadriceps femoris may vary for the different foot positions if the rate of forward lunge is reduced.

Our analysis of the correlation between the tension of the quadriceps femoris and the electromyographic recordings revealed a significant relationship between them for VL, VM and RF. However, the correlation coefficient was found to be smaller for RF, which ranged from 0.22 to 0.39. Therefore, the relationship between the muscular tension and electromyographic findings was low for RF. For VL and VM, a moderate degree of relationship was noted (r=0.57-0.67). Thus, there may be a similarity between the patterns of the muscular activity and expression of the estimated muscular tension.

Hefzy et al.[27] reported that the load on one leg during squat was found to be 50% of the body weight, while that during the forward lunge was 75%. In this study, the load was found to be more than 88% of the body weight. This finding suggested that the load on the muscles was greater during the forward lunge than during squat, and that the forward lunge could therefore be expected to be more effective for muscle strengthening.

Conclusion

Irrespective of the foot position, the quadriceps femoris and TA showed large activity, while BF and GCM were found to be less active. The amount of the muscular activity did not differ among the three foot positions, except for BF and GCM. However, the analysis of the moment revealed differences in the knee extensor moment and the ankle plantarflexor moment regardless of the foot position. A moderate relationship was found between the tension and EMG activities for monoarticular muscles that, in this study, constituted the quadriceps femoris (vasti medialis and lateralis), while it was found to be smaller for the rectus femoris, a biarticular muscle. In conclusion, forward lunge may be efficacious in strengthening VL, VM, RF and Ta and an appropriate functional test that can be used to assess wide varieties of biomechanical dysfunction of the knee.

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足位置の相違による forward lunge 中の筋電図学的および生体力学的分析

三秋　泰一

要　旨

本研究の目的は足位置を変えた lunge の運動パターンを生体力学的および筋電図学的に検討することである。加えて，筋骨格モデルを用い最適化手法により lunge 中の筋張力を推定しその推定された筋張力と筋電図との相関を検討することであった。健常男性18名に lunge 運動を遂行させた。３種類の足位置（Toe in, Neutral, Toe out）でランジ運動を行なわせ，その時の外側広筋（VL），内側広筋（VM），大腿直筋（RF），大腿二頭筋（BF），腓腹筋内側頭（GCM），前脛骨筋（TA）の筋活動パターンと関節モーメントの発揮パターンを検討した。また，Lunge 中の算出された推定筋張力と筋電図の RMS 値との間の相関を検討した。結果は，筋活動パターンにおいては足位置にかかわらず，VL，VM，RF，TA が著明な活動を示し，BF，GCM の活動は運動中を通して低かった。また，RF は VL，VM と比較して活動は低かった。関節モーメントにおいては，Toe in での膝関節伸展モーメントが他の２つの足位置より有意に高かった。また，Toe in の足関節底屈モーメントは，他の２つの足位置でのモーメントより有意に低かった。推定筋張力と筋電図の RMS 値との相関係数は VL では0.58～0.61，VM では0.55～0.67，RF では0.22～0.39であり，すべて有意な相関を示した。本研究の結果より，forward lunge は，大腿四頭筋および前脛骨筋の有効な筋力増強訓練となることが示唆された。